Correlation of the early Albian-late Turonian radiolarian biozonation with planktonic and agglutinated foraminifera zonations in the Pieniny Klippen Belt (Polish Carpathians)

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Bąk M. & Bąk K. 1999. — Correlation of the early Albian-late Turonian radiolarian biozonation with planktonic and agglutinated foraminifera zonations in the Pieniny Klippen Belt (Polish Carpathians), in De Wever P. & Caulet J.-P. (eds), InterRad VIII, Paris/Bierville 8-13 septembre 1997, *Geodiversitas* 21 (4) : 527-537.

ABSTRACT
Marine pelagic deposits of the lower Albian to upper Turonian interval in the Polish part of the Pieniny Klippen Belt are relatively rich in radiolarian fauna as well as in planktonic and agglutinated foraminifera. The proposed radiolarian zones (*Holocryptocanium barbui*, *Hemicryptocapsa prepolyhedra* and *Hemicryptocapsa polyhedra*) have been correlated with planktonic foraminifera biozonation (from *Ticinella primula* to *Dicarinella primitiva* zones), and with agglutinated foraminifera biozonation (from *Haplophragmoides nonioninoides* to *Uvigerinammina* ex gr. *jankoi* zones).

KEY WORDS
Cretaceous,
Radiolaria,
Foraminifera,
integrated biostratigraphy,
Pieniny Klippen Belt,
Carpathians.

RÉSUMÉ
Corrélation des biozones à radiolaires de l'Albien inférieur-Turonien supérieur avec celles à foraminifères planctoniques et agglutinés dans la région des klippes piénines (Carpathes polonaises).
Les dépôts marins pélagiques de l'Albien inférieur-Turonien supérieur de la zone des klippes piénines sont relativement riches en faune de radiolaires, ainsi que de foraminifères planctoniques et agglutinés. Les zones de radiolaires proposées (*Holocryptocanium barbui*, *Hemicryptocapsa prepolyhedra* et *Hemicryptocapsa polyhedra*) sont en correlation directe avec les biozones de foraminifères planctoniques (de la zone *Ticinella primula* à la zone *Dicarinella primitiva*) et celles des foraminifères agglutinés (de la zone *Haplophragmoides nonioninoides* à la zone *Uvigerinammina* ex gr. *jankoi*).

MOTS CLÉS
Crétacé,
Radiolaria,
Foraminifera,
biostratigraphie intégrée,
zone des klippes piénines,
Carpathes.

INTRODUCTION

Detailed micropalaeontological studies of marine pelagic Cretaceous deposits have been carried out in the Pieniny Klippen Belt during the last 15 years. A part of these concerned biostratigraphy, based on different groups of microfauna: foraminifera (Birkenmajer & Jednorowska 1987; Gasiński 1988; Kostka 1993; K. Bąk 1998), nannoplankton (Dudziak 1985), dinocysts (Jamiński 1990) and radiolaria (M. Bąk 1995; 1996a, b). However, only very few studies comprise an integrated biostratigraphy of these deposits (Birkenmajer *et al.* 1979; K. Bąk *et al.* 1995).

The Cretaceous deposits of the Pieniny Klippen Belt provide the best material for the integrated biostratigraphical studies in the whole Carpathians, because they represent pelagic and hemipelagic calcareous-marly facies, and contain abundant microfauna. These deposits have been formed in the Pieniny Klippen Basin (Birkenmajer 1977), a part of the Penninic Ocean-northern part of Western Tethys (Fourcade *et al.* 1993) (Fig. 1A). The sedimentation during Albian through Campanian took place under deep-water conditions, at outer shelf through lower bathyal/abyssal depths, above or near CCD (Birkenmajer & Gasiński1992; K. Bąk 1995a, b). They crop out in a highly tectonically deformed zone, known as the Pieniny Klippen Belt, that separates the Inner from the Outer Carpathians (Fig. 1B, C).

The present authors propose here an integrated local biostratigraphy based on planktonic Foraminifera, agglutinated Foraminifera and Radiolaria for early Albian through late Turonian time span. The correlation is based on studies of microfauna from the same samples within the same sections. Foraminifera and Radiolaria are relatively abundant in the studied deposits.

GEOLOGICAL SETTING AND RADIOLARIAN HORIZONS

Twenty five sections located at Niedzica, Krościenko, Szczawnica, Jaworki, Sromowce, Dursztyn, Szaflary and Stare Bystre have been chosen for integrated micropalaeontological analyses. A detailed description of profiles, sample location, and lithology is given in papers by K. Bąk (1992, 1993, 1998) and M. Bąk (1995, 1996a, b, 1997). In 18 of these sections, radiolarian skeletons have been found together with foraminifera, and the best sections (15) were used here for correlation purposes (Figs 1, 2).

In the sections examined, the microfauna has been recovered from the deposits of the Kapuśnica and Jaworki formations. Lithological features, thickness and age of these lithostratigraphical units, distinguished by Birkenmajer (1977, 1987), and Birkenmajer & Jednorowska (1984) and presented below, concern only the studied sections.

Kapuśnica Formation

This formation is subdivided in two members, the Brodno Member and the Rudina Member, both represented in the sections investigated.

The Brodno Member. It has been identified only in the one section as a 40 cm thick layer of black marls, ? upper Aptian in age. The radiolarian fauna is present but very rare in these deposits.

The Rudina Member. (1-20 m thick; lower-upper Albian) It is represented by green-grey and black marls and marly shales with marly limestone intercalations, with red marls appearing in the upper part. Abundant and well-preserved radiolarian skeletons are present in green and black marls and marly shales.

Jaworki Formation

Deposits of the Jaworki Formation have been examined in sections belonging to all Klippen successions (Fig. 2).

The Brynczkowa Marl Member. (2-22 m thick; Vraconian-middle Cenomanian) It consists of green or grey-green marls with thin scarce red marl intercalation. Moderately to poorly preserved radiolaria are rare.

The Skalski Marl Member. (4-15 m thick; middle-upper Cenomanian) It consists of variegated marls, intercalated with green, red and grey marls. Except of the Altana Shale Bed, the radiolarians are present in this member but are rare and mostly poorly preserved.

The Altana Shale Bed. (0.4-3 m thick;

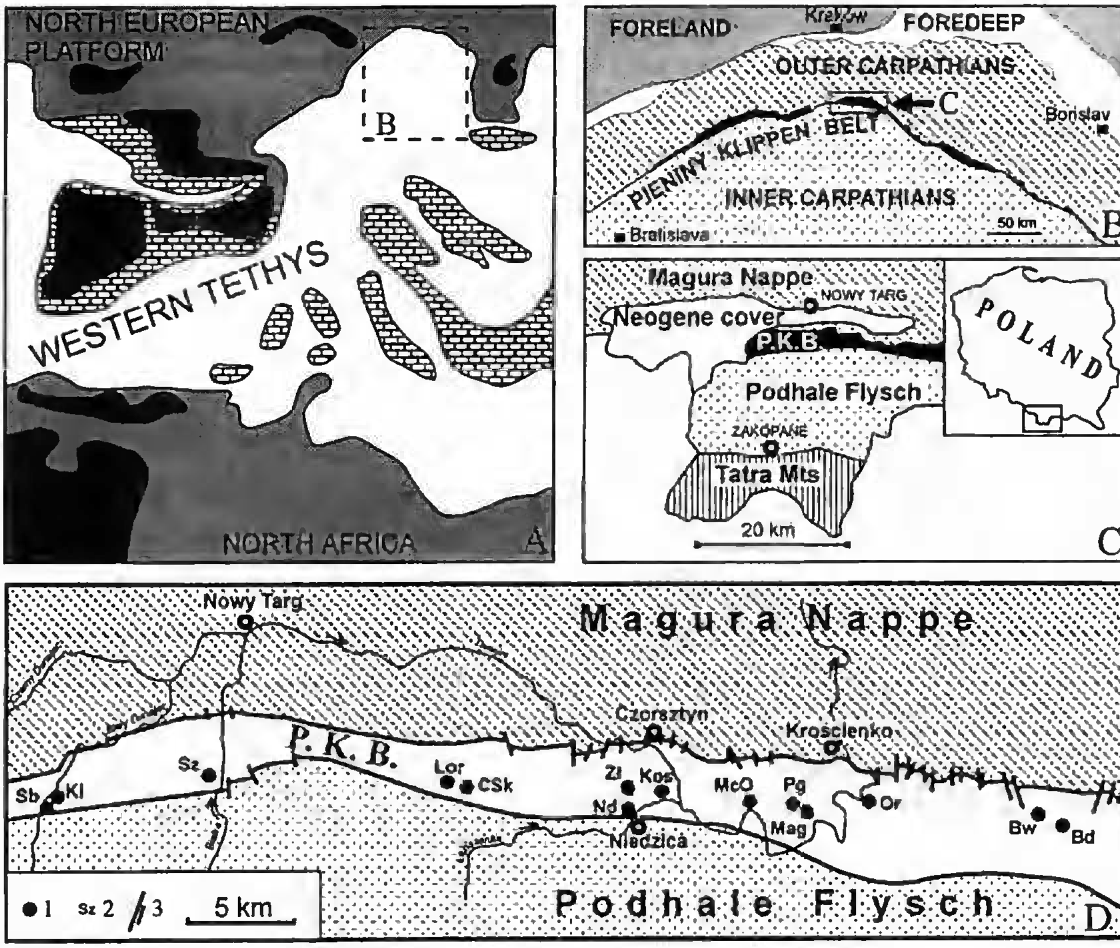

FIG. 1. — Location of the study area: **A**, in the Western Tethys (rectangle B) (map of late Cenomanian palaeoenvironments after Fourcade *et al.* 1993; simplified); **B**, **C**, in the Carpathians (Pieniny Klippen Belt in black); **D**, in the Pieniny Klippen Belt. Legend: **1**, investigated outcrops; **2**, symbols of outcrops; **3**, more important dislocations. List of outcrops (from west to east): **Sb**, Stare Bystre; **Kl**, Kietowy stream; **Sz**, Szaflary quarry, **Lor**, Lorencowe Klippes; **Csk**, Czerwona Skała; **Zl**, Złobowy Creek; **Nd**, Niedziczanka stream; **Kos**, Kosarzyska Valley; **McO**, Macelowa-Osice; **Pg**, Podskalnia Góra Mt; **Mag**, Magierowa Klippe; **Or**, Orlica Hill; **Bw**, Bukowiny Valley; **Bd**, Bukowiny Hill.

Cenomanian/Turonian boundary) It consists of black-blue, greenish and black shales and marly shales. Radiolarians are abundant but low-diversified and poorly preserved. Their pyritized skeletons are mostly found within the Czorsztyn Succession deposits.

The Magierowa Marl Member. (9 m; Cenomanian/Turonian boundary) It is represented by shales, marly shales, marls, and thin-bedded marly limestone of grey to green colour with black alternations. Radiolarian fauna is abundant: well-preserved siliceous specimens are present in green and grey shales and marly shales. The radiolarians are also abundant in black shales but are often difficult to determine, because of Fe-oxide coating and pyritization.

The Trawne Member. (5 m; lower-middle Cenomanian) It consists of grey-green marls and shaly marls with sandstone intercalations. Radiolarian fauna is scarce: only a few poorly preserved specimens have been found.

The Snežnica Siltstone Member. (3-? 40 m;

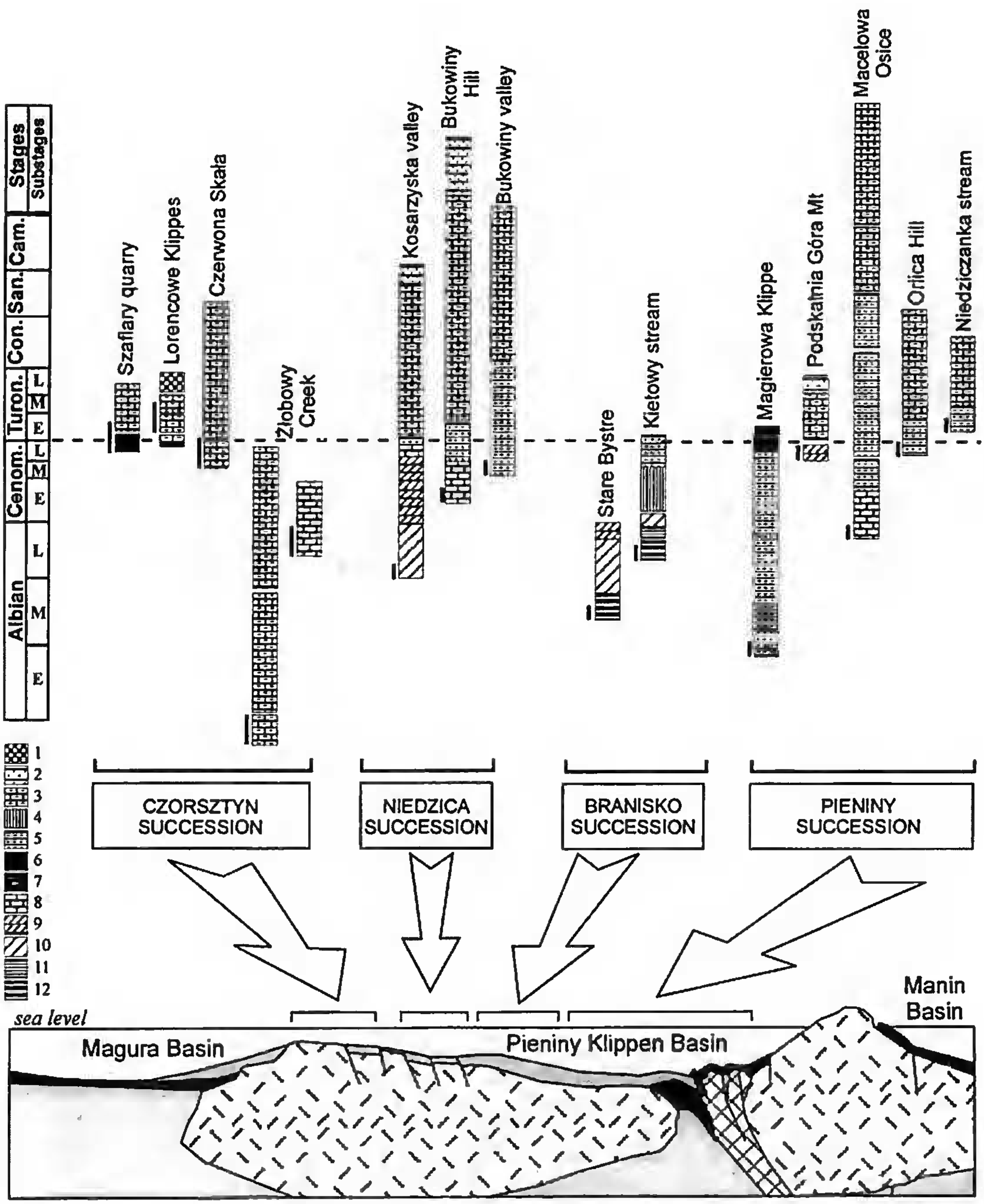

FIG. 2. — Lithological columns of the studied sections in relation to the age of deposits (dashed line corresponds to the Cenomanian/Turonian boundary) and their attribution to Klippen successions and sedimentary zones [Pieniny Klippen Basin reconstruction after Birkenmajer (1977)]. Lithological units investigated [lithostratigraphy after Birkenmajer (1977, 1987), Birkenmajer & Jednorowska (1984)]: **1**, Lorencowe Chert Bed; **2**, Osice Siltstone Member; **3**, Macelowa and Pustelnia Marl members; **4**, Trawne Member; **5**, Snežnica Siltstone Member; **6**, Altana Shale Bed; **7**, Magierowa Member; **8**, Skalski Marl Member; **9**, Brynczkowa Marl Member; **10**, Rudina Member; **11**, Brodno Member; **12**, Pieniny Limestone Formation. Scale bars: 5 m, except of Branisko Succession sections, 1 m.

middle Cenomanian-middle Turonian) It is represented by alternating bright blue-grey and green shaly marls with thin-bedded siltstone and sandstone, and bright-green pelitic limestone intercalations. Radiolarians are rare in this member, but the upper Cenomanian deposits are enriched in well-preserved, pyritized radiolarian skeleton.

The Macelowa Marl Member. (15-70 m; lower Cenomanian-Santonian) It consists mostly of red marls and marly limestone with thin intercalations of greenish or bluish siltstones and sandstones which appear in its lower and upper parts. Poorly preserved and mainly calcified radiolarians are present in this member. They are diversified, especially those found in a horizon corresponding to the lower-middle Turonian.

The Pustelnia Marl Member. (6-45 m; middle Cenomanian-Santonian) It consists of pure brick-red, strongly tectonized marls without clastic intercalations. Radiolarian skeletons are very scarce, poorly preserved, and mainly calcified.

The Lorencowe Chert Bed. (3 m; upper Santonian-lower Campanian) It is represented by a two-meter-thick complex consisting of alternating variegated marls (mostly red) with thin intercalations of light-green limestone. Radiolarian skeletons are also scarce, poorly preserved, mostly calcified.

RADIOLARIAN ASSEMBLAGES

Seventy seven radiolarian species have been determined from the Cretaceous deposits ranging from lower Albian to Santonian of the Pieniny Klippen Belt: 20 genera and 53 species of Nassellaria, and 11 genera and 24 species of Spumellaria were recognised (M. Bąk 1997).

The assemblages, in all Klippen successions investigated, are dominated by cryptocephalic and cryptothoracic Nassellaria belonging to the genera *Holocryptocanium*, *Hemicryptocapsa*, *Cryptamphorella*, *Dorypyle*, *Hiscocapsa*, *Trisyringium* and *Squinabollum*. Multisegmented Nassellaria are also common being represented by the genera *Dictyomitra*, *Thanarla*, *Pseudodictyomitra*, *Stichomitra*, *Xitus*, *Obeliscoites* and *Torculum*. Spumellaria are less common; the most abundant are the specimens belonging to the families Actinommidae, Praeconocaryommidae, Xiphostylidae (genera *Staurosphaeretta* and *Triactoma*), and Dactyliosphaeridae (*Dactyliodiscus*, *Godia* and *Dactyliosphaera*). Other Spumellaria belong to the genera *Hexapyramis*, *Cavaspongia*, *Pseudoaulophacus*, *Patellula*, *Paronaella* and *Crucella*.

Within the Klippen successions investigated, the radiolarians are most abundant and diversified in the Czorsztyn Succession deposits (outer shelf-upper bathyal environment), becoming generally scarce in the deposits of the Pieniny Succession (lower bathyal environments, close to Calcium Compensation Depth).

The radiolarian specimens are most abundant and diverse in green and black marly shales, marls and limestones of the Kapuśnica and Pomiedznik formations, the Magierowa Member and the Altana Shale Bed of the Jaworki Formation. They are scarce in red and variegated marls and shales of the Macelowa Marl, Brynczkowa Marl and the Skalski Marl members of the Jaworki Formation. This might be dependent on lithology and diagenesis factors responsible for preservation of siliceous microfossils; however, radiolarian faunas radiation and turnovers could be also taken into account. Both causes might reflect an ecological response of marine biota to global climate and sea level changes during mid-Cretaceous times.

Two great changes in the radiolarian assemblages have been recorded within the studied deposits:

1. Beginning of an important first radiation of Radiolaria occurred during the middle Albian (*Ticinella primula* foraminiferal zone, K. Bąk 1992) as many new species had their first appearance in the middle and the late Albian. The maximum of differentiation in the radiolarian assemblage is observed in the Vraconian deposits (*Rotalipora ticinensis* through the *Rotalipora appenninica-Planomalina buxtorfi* foraminiferal zones, K. Bąk 1998). Starting from the upper part of the *R. appenninica-P. buxtorfi* foraminiferal zone towards the Cenomanian/Turonian boundary, a relative decrease in the number of species occurred. As a result, the radiolarian faunas in the Czorsztyn, Branisko and Niedzica successions show great similarities. The same characteristic taxa from the suborder Nassellaria (both cryptothoracic and cryptocephalic forms) represented by the genera *Holocryptocanium*, *Hemicryptocapsa*, *Squinabollum* and *Cryptamphorella* are the most abundant, while the genera *Dictyomitra*, *Pseudodictyomitra*, *Thanarla*, *Stichomitra*, *Torculum*, and *Xitus* are also common.

2. The next change in radiolarian assemblages took place around the Cenomanian/Turonian boundary. It started during the late Cenomanian (*Rotalipora cushmani* foraminiferal zone, K. Bąk 1998). At that time, the radiolarian assemblages from the Pieniny Succession became similar to those from the Czorsztyn, Niedzica and Branisko successions. Moreover, it was enriched in forms described so far only from the Silesian and the Skole units of the Outer Flysch Carpathians (*Praeconocaryomma lipmanae*, *Godia* sp., *Diacanthocapsa* sp. – see M. Bąk 1994; Górka 1996).

FORAMINIFERAL ASSEMBLAGES

The early and middle Albian Foraminifera in the Pieniny Klippen Belt represent a well-diversified assemblage. Planktonic forms prevail, being represented by hedbergellids (*H. delrioensis*, *H. planispira* and *H. simplex*), *Globigerinelloides bentonensis*, and ticinellids (*Ticinella primula*, *T. roberti*) (K. Bąk 1992). Benthos is dominated by calcareous forms with the most frequent *Gyroidinoides infracretacea*, *Gavelinella cenomanica* and *G. intermedia*, and accompanied by *Dentalina* sp., *Nodosaria* sp. and *Lenticulina* sp. Agglutinated foraminifera (predominantly infaunal forms) are infrequent in these deposits, with *Dorothia gradata*, *Spiroplectinata annectens*, *Tritaxia gaultina* and *Textularia foeda* prevailing.

The upper Albian planktonic Foraminifera are very numerous and more diversified. Besides the most frequent hedbergellids, *Biticinella breggiensis*, *Planomalina buxtorfi*, *Globigerinelloides bentonesis*, *G. ultramicra*, praeglobotruncanids and rotaliporids occur there. Benthos is very rare, dominated by calcareous forms, similar to those present in the older assemblage.

A very similar assemblage is also characteristic of the Cenomanian deposits: planktonic Foraminifera prevail there, with dominating rotaliporids, associated with representatives of the genera *Praeglobotruncana*, *Hedbergella*, *Whiteinella*, *Globigerinelloides*, *Heterohelix* and *Shackoina*. Ratio of calcareous to agglutinated benthic forms is different in pelagic and hemipelagic deposits of this stage. Agglutinated taxa prevail (more than 80% of benthos) in the scaglia rossa-type (Macelowa Marl Member) and flyschoid deposits (Trawne Member, Snežnica Siltstone Member), being dominated by *Plectorecurvoides alternans*, *Recurvoides* sp., *Bulbobaculites* sp., *Trochammina* sp., *Haplophragmoides* sp., *Spiroplectammina navarroana*, *Arenobulimina preslii*, *Dorothia* sp., *Tritaxia* sp., *Glomospira* sp., and by tubular forms.

Calcareous forms are more frequent in variegated and red pelagic marls (Bryneżkowa Marl, Skalski Marl and Pustelnia Marl members). However, they are represented by single specimens only. Agglutinated foraminifers include the genera *Dentalina*, *Nodosaria*, *Tristix*, *Lenticulina*, *Marginulinopsis*, *Marginulina*, *Saracenaria*, *Astacolus*, *Planularia*, *Globulina*, *Oolina*, *Pyrulina*, *Ramulina*, *Praebulimina*, *Pleurostomella*, *Valvulineria*, *Pullenia*, *Osangularia*, *Gyroidinoides*, *Gavelinella*, *Lingulogavelinella* and *Eponides*.

A quite different foraminiferal assemblage appears in black shale facies close to the Cenomanian/Turonian boundary. Planktonic Foraminifera are still frequent in the lower part of the shales, being represented predominantly by *Rotalipora cushmani*; they are accompanied by whiteinellids, praeglobotruncanids, hedbergellids and single forms from the genera *Globigerinelloides* and *Heterohelix*. In a higher part of the shales, only single forms of *Praeglobotruncana delrioensis* and *Hedbergella delrioensis* have been found. Benthonic forms are dominated by very frequent *Lenticulina gaultina*. This form is accompanied by single specimens of agglutinated foraminifera from the genera *Bulbobaculites*, *Trochammina*, *Hormosina*, *Glomospira*, *Ammodiscus* and *Rhizammina*.

The middle-late Turonian foraminiferal assemblage considerably differs from the Cenomanian one. Middle Turonian was the acme of *Helvetoglobotruncana helvetica* and *H. praehelvetica* which characterise this assemblage, while benthonic forms are almost absent. During the late Turonian, benthonic forms become more frequent, and they prevail in the latest Turonian deposits. The benthos is dominated by agglutinated taxa (more than 90%) with very characteristic *Uvigerinammina jankoi*, *Recurvoides godulensis*, *Gerochammina conversa*, *Karrerulina coniformis*, *Haplophragmoides* cf. *bulloides* and *Bulbobaculites problematicus*. Calcareous benthos is represented predominantly by the genera *Eponides*, *Stensioeina* and *Gyroidinoides*.

RADIOLARIAN BIOSTRATIGRAPHY

Radiolarian species were identified in more than 200 samples from 18 sections in the deposits of the Pieniny, Branisko, Niedzica and Czorsztyn successions of the Pieniny Klippen Belt (M. Bąk 1997). Seventeen horizons containing abundant and well-preserved Radiolaria have been chosen for closer analysis (M. Bąk 1999); the BioGraph 2.02 computer program (Savary & Guex 1991) based on the Unitary Associations Method was applied. This program produced a sequence of 11 U. A. (Fig. 3), which were used for constructing a radiolarian zonal standard (M. Bąk 1999). Three radiolarian zones and five subzones were proposed for the early Albian through late Turonian time span (Fig. 3). These are: (1) the *Holocryptocanium barbui* zone with *Stichomitra tosaensis*, *Squinabollum fossile*, *Thanarla veneta*, *Torculum dengoi* and *Obeliscoites maximus* subzones; (2) the *Hemicryptocapsa prepolyhedra* zone; (3) the *Hemicryptocapsa polyhedra* zone. The top of each zone and subzone is defined by the FAD of the index taxon and also by the base of the overlying zone.

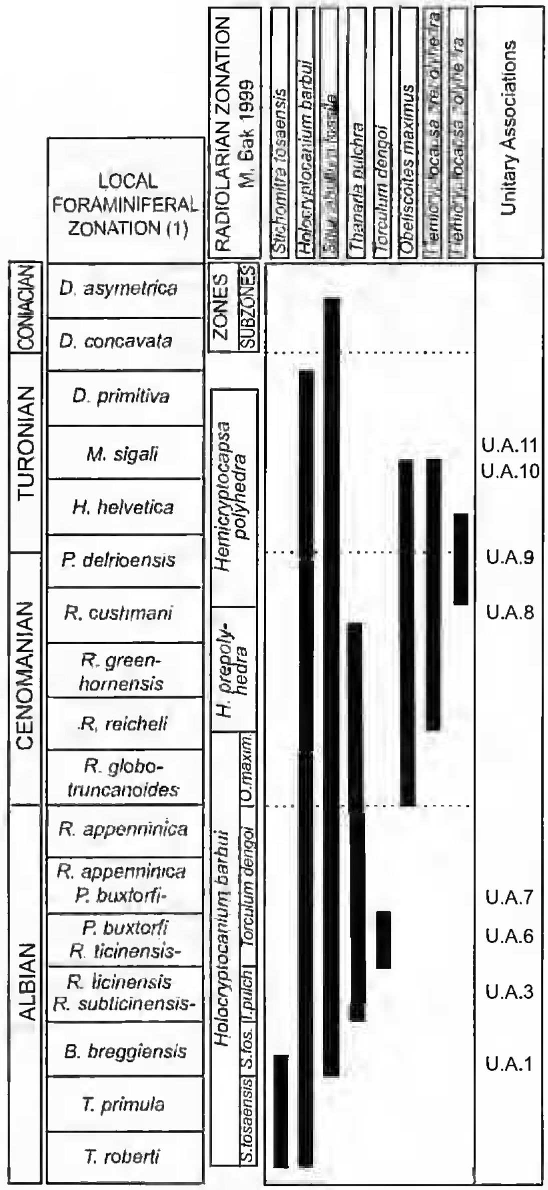

FIG. 3. — Occurrence range chart of index radiolarian species recorded in the Albian to Coniacian deposits in the Pieniny Klippen Belt successions, based on their first and the last appearances, and their co-occurrence based on the Unitary Associations. Abbreviations of zones: **S. tosaensis**, *Stichomitra tosaensis*; **S. fos.**, *Squinabollum fossile*; **T. pulch.**, *Thanarla pulchra*; **O. maxim.**, *Obeliscoites maximus*. **1**, local planktonic foraminiferal zonation after Robaszynski & Caron (1985) modified by K. Bąk (1992, 1998).

FORAMINIFERAL BIOSTRATIGRAPHY

Extensive biostratigraphical studies based on planktonic foraminifera were carried out in Cretaceous deposits of the Polish part of the Pieniny Klippen Belt (Alexandrowicz 1966; Alexandrowicz *et al.* 1968a, 1968b; Jednorowska 1979; Gasiński 1983, 1988; Birkenmajer & Jednorowska 1987; Kostka 1993). The local biozonations have been tied to the zonal standards of the Western Tethys.

The local planktonic biozonation here presented (K. Bąk 1992, 1998), is based on studies of 18 field sections (more than 270 samples) representing deposits from all sedimentary zones of the Pieniny Klippen Basin in Poland. The zones distinguished and their chronostratigraphic calibration, correspond very well with the Mediterranean zonal standard as proposed by Robaszynski & Caron (1995), with only minor revision (for more details, see K. Bąk 1998).

The biozonation based on agglutinated foraminifera follows that proposed for Outer Carpathians by Geroch & Nowak (1984), and applied also to the Pieniny Klippen Belt (K. Bąk *et al.* 1995).

CORRELATION OF RADIOLARIAN ZONATION WITH PLANKTONIC AND AGGLUTINATED FORAMINIFERA ZONES

Various radiolarian zonations for the late Cretaceous deposits were proposed depending on the area concerned. Two proposed standards calibrated with chronostratigraphy in the western part of the Tethys deserve special attention. The first standard was proposed by Dumitrică (1975) for the Romanian Carpathians. He recognised two radiolarian assemblages, the older assemblage and the younger one correlated with planktonic foraminifera. The *Holocryptocanium barbui-H. tuberculatum* assemblage corresponds, according to Dumitrică (1975), to the *Rotalipora reicheli-R. cushmani* zone (latest Cenomanian).

O'Dogherty's (1994) standard was more detailed and comprised a calibration with the Northern Apeninnes and Betic Cordillera. This calibration has been based on planktonic Foraminifera partially following the zonal standard as proposed by Caron (1985), with some modifications. O'Dogherty (1994) recognised five radiolarian zones correlated with the *Hedbergella sigali* (Barremian) through the *Marginotruncana sigali* (late Turonian) foraminiferal zones.

In this study, we propose a correlation of radiolarian zones with planktonic and agglutinated foraminiferal zones for the early Albian through late Turonian time span, for the Polish part of the Pieniny Klippen Belt (Fig. 4).

The definition of the *Holocryptocanium barbui* zone used in this zonation follows that of Schaaf's (1985), with some modification of its upper limit. The lower boundary of *H. barbui* zone (= lower boundary of the *Stichomitra tosaensis* subzone) is not well defined, because the earliest Albian and latest Aptian (*Ticinella roberti* planktonic foraminiferal zone and *Haplophragmoides nonioninoides* agglutinated foraminiferal zone) deposits are not well represented in the sections investigated, their radiolarian fauna is rare and poorly preserved. The upper boundary of the *H. barbui* zone falls within a lower part of the *Rotalipora reicheli* planktonic foraminiferal zone and the *Bulbobaculites problematicus* agglutinated foraminiferal zone (middle Cenomanian). The *Squinabollum fossile* radiolarian subzone coincides with the *Biticinella breggiensis* foraminiferal zone (Late Albian). The *Thanarla pulchra* subzone coincides with the *Rotalipora ticinensis-R. subticinensis* foraminiferal zone (late Albian). The lower limit of the *Torculum dengoi* subzone correlates with the upper boundary of the *Rotalipora ticinensis-R. subticinensis* foraminiferal zone. Its upper limit correlates with the upper boundary of the *Rotalipora appenninica* foraminiferal zone (Albian/Cenomanian boundary), and also coincides with the lower limit of the *Obeliscoites maximus* subzone.

The lower boundary of the *Hemicryptocapsa prepolyhedra* zone corresponds to a lower part of the *Rotalipora reicheli* planktonic foraminiferal zone (middle Cenomanian). Its upper boundary (= lower boundary of the *Hemicryptocapsa polyhedra* zone) corresponds to an upper part of the *R. cushmani* planktonic foraminiferal zone (late Cenomanian). The upper boundary of the *H. polyhedra* zone has not been defined within the deposits investigated because the Radiolaria from the latest Turonian and the Coniacian are very poorly preserved (mostly calcified). This zone correlates with the *Rotalipora cushmani* through *Dicarinella primitiva* planktonic foraminiferal zones (= upper part of *Bulbobaculites problematicus* and lower part of *Uvigerinammina* ex gr. *jankoi* agglutinated foraminiferal zones; late Cenomanian through late Turonian).

It is hoped that the proposed radiolarian zonal standard will become a calibration tool to which

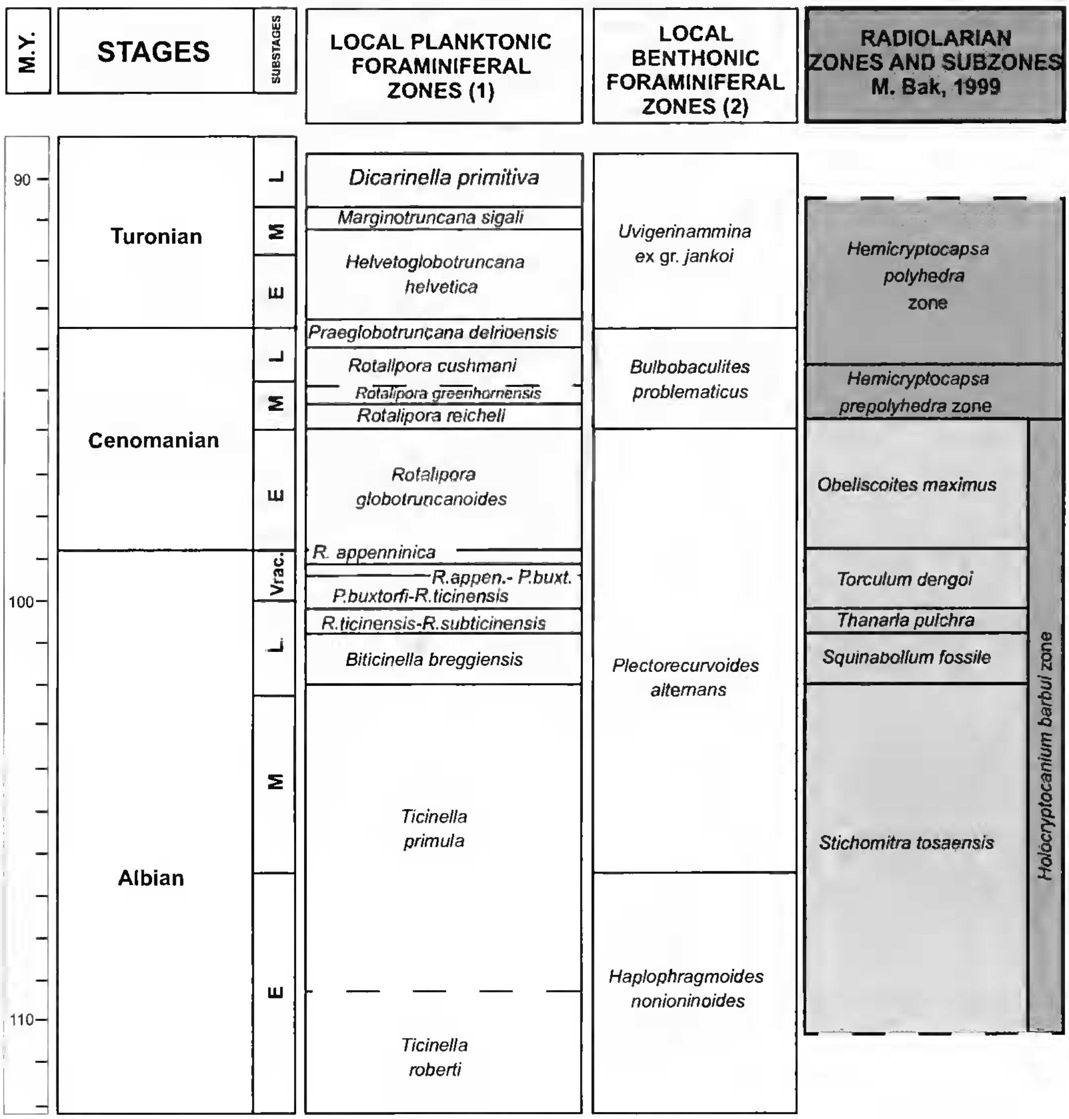

FIG. 4. — Correlation of radiolarian biozones and subzones with planktonic and agglutinated Foraminifera zonations in the Pieniny Klippen Belt, Polish Carpathians [chronological scale after Robaszynski & Caron (1995)]. **1**, local planktonic foraminiferal zonation after Robaszynski & Caron (1985) modified by K. Bąk (1992, 1998); **2**, local benthonic foraminiferal zonation after Geroch & Nowak (1984) modified by K. Bąk *et al.* (1995), K. Bąk (1995a).

local zonations from other Carpathian regions could be correlated.

Acknowledgements

The authors are greatly indebted to Prof. K. Birkenmajer (Institute of Geological Sciences, Polish Academy of Sciences, Kraków) for valuable editorial comments. Particular thanks are due to Prof. M. Caron (Institut de Géologie de l'Université, Fribourg) and Dr. P. Dumitrică (Institut de Géologie et Paléontologie, Université de Lausanne) who revised the manuscript. Mrs I. Chodyń (Institute of Geological Sciences, Jagiellonian University, Kraków) helped us in the laboratory part of the work. This research is a

contribution of the IGCP 362 Project, Tethyan and Boreal Cretaceous.

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Submitted for publication on 1 April 1998; accepted on 18 February 1999.